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Conservation Tillage and Cover Crop Influences on Cotton Production on a Southeastern U.S. Coastal Plain Soil

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ABSTRACT

Understanding cover crop and tillage system interactions within specific environments can help maximize productivity and economic returns of cotton (*Gossypium hirsutum* L.) produced on sandy coastal plain soils of the southeastern USA. A strip-plot design with three replications was used to evaluate the cover crops Austrian winter pea [*Pisum sativum* L. ssp. *arvense* (L.)], balansa clover (*Trifolium michelianum* Savi), crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia villosa* Roth subsp. *villosa*), oil seed radish (*Raphanus sativus* L.), black oat (*Avena strigosa* Schreb.), and rye (*Secale cereale* L.) and tillage (strip and none) influences on cotton grown on a Bonifay fine sand (loamy, siliceous, subactive, thermic Grossarenic Plinthic Paleudults) near Waynesboro, GA from 1999 to 2003. Drought influenced production 3 of 4 yr. Cover crop biomass was greatest from rye, intermediate from black oat, oilseed radish, hairy vetch, and Austrian winter pea. Hairy vetch and Austrian winter pea contained more than 80 kg N ha^{-1} while other cover crops averaged <40 kg N ha^{-1}. Cotton yields following black oat and rye had returns above variable costs ha^{-1} \$461 and \$406, respectively. Strip-tillage increased yields by 192 kg ha^{-1} and annual returns by \$112 ha^{-1} over no-tillage, most likely due to improved available water. Combining strip-tillage with black oat was the best combination for maximizing profit. Using black oat with strip-tillage could increase cotton profit by \$50 to \$75 ha^{-1} compared to systems using rye on the 1.45 million ha of cotton where conservation systems have been adopted.

Conservation tillage systems offer significant environmental and economic advantages for growing cotton in the southeastern USA (Bruce et al., 1995). Adoption of conservation tillage systems for cotton in the Southeast has grown to nearly 50% on the 2.9 million ha planted in 2004 (CTIC, 2005). Implementation of the Conservation Security Program in the USDA 2002 Farm Bill should provide a stimulus for increased adoption of conservation tillage systems because payments increase as producers meet higher standards of conservation and environmental management. Achieving greater levels of conservation and environmental management requires regionally specific information about how cropping system components interact so that producers can select the best combination of practices for their farming conditions (Schomberg et al., 2003).

The southeastern U.S. Coastal Plain is humid subtropical with an average rainfall of about 1100 mm yr^{-1}. Many Coastal Plain soils are sandy with low water-holding capacities and often have compacted subsurface layers that further limit water availability for crop growth. Deep tillage or in-row subsoiling is generally recommended to increase the volume of soil that plant roots explore for water and nutrients (Vepraskas and Guthrie, 1992; Raper et al., 1994; Reeves and Mullins, 1995; Mullins et al., 1997; Zou et al., 2001; Rosolem et al., 2002) thereby increasing yield potential (Threadgill, 1982; Busscher et al., 1995; Frederick et al., 1998; Busscher et al., 2000). Many producers in the Coastal Plain use "strip-tillage" which includes coulters, rolling baskets, and in-row subsoiling with a 20- to 50-cm shank to disrupt compacted layers when first converting to conservation tillage (Busscher et al., 1995; Busscher and Bauer, 2003). Although this system disturbs a 15- to 30-cm wide zone, the undisturbed interrow surface area remains covered by residues which help reduce erosion and evaporative water loss (Kaspar et al., 1990). The tilled zone allows operation of conventional planters and fertilizer applicators and promotes faster warming of soil (Kaspar et al., 1990) in the spring which can increase germination rates. Improved water use efficiency in strip-tilled soil can increase cotton production up to 35% compared to that in conventional tilled soil (Lascano et al., 1994).

Responses to deep tillage in these soils can be variable because of inherent differences in crop growth, soil type, and tillage tools (Bodhinayake et al., 1998; Rosolem et al., 2002; Busscher and Bauer, 2003). Cropping practices may also have an influence on response to deep tillage. Raper et al. (2000) found no benefit to strip-tillage in spring compared with strict no-tillage on soils of the Tennessee River Valley in northern Alabama when a rye cover crop was used. Cover crops appear to reduce compaction or recompaction by minimizing traffic effects or by disrupting compaction during periods when the water content is favorable for plant growth (Ess et al., 1998; Raper et al., 2000; Rosolem et al., 2002).

Maximizing conservation system productivity in the southeastern USA requires additional biomass inputs provided by cover crops because they are essential for improving and maintaining soil biological, chemical, and physical properties (Langdale et al., 1990). Winter cereals are effective cover crops in the region because they establish rapidly, provide good winter ground cover and produce consistent amounts of biomass. Legume cover

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Abbreviations: GDD, growing degree days; NIRS, near infrared reflectance spectroscopy.

crops are less frequently used but have the potential for reducing fertilizer inputs (costs) through fixation of atmospheric N_2. The choice of cover crop and residue management can be complicated because of the potential for positive or negative impacts on summer crop production. Surface residues can interfere with planting operations and result in poor seed to soil contact (Grisso et al., 1984) while incorporated residues may impact stand establishment through the action of allelopathic compounds (White and Worsham, 1989; Rickerl et al., 1989). Bauer and Busscher (1996) found a positive effect of rye on cotton yields compared to legumes or fallow with conservation tillage but observed no difference in cotton yields among cover crop treatments with conventional tillage. Additionally, cover crop influences on N mineralization–immobilization processes can reduce N availability (Aulakah et al., 1991; Doran and Smith, 1991; Schomberg and Endale, 2004) which must be considered in determining fertilizer recommendations because of the critical effects of N on cotton yield (Mullins and Burmester, 1990).

These results indicate that site and management specific differences influence crop response to conservation tillage and cover crop systems. Although considerable data exists on cotton production following rye, vetch, and clover as cover crops, we need to expand the cover crop resource base and develop additional information for new cover crop-tillage system combinations to assist in the selection of appropriate systems for conservation program compliance. Our objectives were to (i) evaluate four relatively unused and untested cover crops for growth and N accumulation in no-tillage and strip-tillage cotton production systems and (ii) to evaluate the impact of these cover crops on cotton production on a sandy coastal plain soil.

MATERIALS AND METHODS

The study was initiated in fall of 1999 at the Central Savannah River Area Conservation Tillage Demonstration Farm near Waynesboro, GA, on a Bonifay fine sand (1–3% slope). The experiment used a strip-plot design with three replications to evaluate the effects of seven cover crops and two tillage systems on the growth and yield of cotton from 2000 to 2003. Austrian winter pea, 'Paradana' balansa clover, 'AU-Sunrise' crimson clover, hairy vetch, common oil seed radish, 'IAPAR-61' black oat and 'Wrens Abruzzi' rye were planted with a Great Plains no-tillage grain drill (4.6-m wide, 19.0-cm rows) (Great Plains Mfg., Salina, KS) at 39, 11, 17, 22, 28, 28, and 84 kg seed ha^{-1}, respectively. Cover crops were planted in plots 18.2 by 23.2 m on 15 Oct. 1999, 13 Nov. 2000, 20 Nov. 2001, and 20 Nov. 2002. All plots received an application of 17 kg N ha^{-1} and 25.6 kg P ha^{-1} as $(NH_4)_2HPO_4$ and 104 kg K ha^{-1} as KCl each year after planting. The 14 kg starter N was applied to all crops to help with early growth and establishment on this very sandy soil and would not inhibit N_2 fixation by the legumes (Schomberg and Weaver, 1990). Just before planting, approximately 25 mm of water was applied through a pivot irrigation system to facilitate planting and a similar amount of water was applied 5 to 7 d after planting in 1999, 2000, and 2001 to ensure germination and stand establishment.

Cover crop biomass was determined during the third week of April by clipping plants near the soil surface in three to four 0.5 m^2 quadrats within each plot. The biomass was placed in a forced draft oven at 55°C for 5 to 7 d until dry, weighed and then ground for determination of C and N content using near infrared reflectance spectroscopy (NIRS) calibrated to a combustion type C–N analyzer. Cover crops were terminated using glyphosate (*N*-(phosphonomethyl)glycine) 5 to 7 d after sampling for biomass.

Strip-tillage and no-tillage plots for the cotton growing season were established in strips 12 rows wide (11.6 m) that extended across the length of the cover crop plots (127.7 m). Tillage by cover crop subplots were therefore 11.6 m wide by 18.2 m long. A four-row strip-tillage unit (Kelly Manufacturing Company, Tifton, GA) that had a 40.6 cm in-row chisel, three 36-cm diameter coulters and rolling basket residue handlers was used for the strip-tillage treatment. The unit created a clean tilled strip 30-cm wide in each row. A four-row Monosem No-Till Planter (A.T.I., Monosem, Lenexa, KS) set on 96.5 cm centers was used to plant cotton at 8 to 10 kg seed ha^{-1} in all plots. Cotton varieties and planting dates were Stoneville 474 RR- 26 May 2000, Suregrow 501 B/RR- 28 May 2001, DPL 458 B/RR- 27 May 2002, and DPL 458 B/RR- 21 May 2003. We applied 25 mm of water before and following cotton planting and again approximately 10 d after planting to facilitate stand establishment, except in 2003 when significant rain fell. Fertilizer P, K, and lime applications were based on soil test recommendations from the University of Georgia Soil and Plant Analysis Laboratory. Nitrogen was applied at 80 kg N ha^{-1} as NH_4NO_3 to all plots as a split application with 25% applied at planting and the remainder applied about 4 wk later. Weeds were controlled in 1999 with applications of fluometuron [1,1-dimethyl-3-(α,α,α,-trifluoro-m-tolyl)urea] (1.1 kg a.i. ha^{-1}) and pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2-6,-dinitrobenzenamine] (0.84 kg a.i. ha^{-1}) at planting, followed by an application of glyphosate at 1.1-kg a.i. ha^{-1} sprayed over the cotton at the three to four leaf stage. Aldicarb [2-methyl-2-(methylthio)-propionaldehyde *O*-(methylcarbamoyl) oxime] was applied at 0.84 kg a.i. ha^{-1} as granules in-furrow at planting for the early-season thrips (Frankliniella spp. Karny) control. Insects during the cotton growing season were controlled with one to two applications of lambda-cyhalothrin at 0.028 to 0.044 kg a.i. ha^{-1}. Cotton was harvested on 26 Oct. 2000, 13 Nov. 2001, 31 Oct. 2002, 17 Oct. 2003 using a two- or four-row cotton picker.

Irrigation was applied to cotton at planting (25–30 mm) through a pivot irrigation unit to assist with stand establishment. Water availability was limited during the growing season in 2000 and 2001 because ponds used for irrigation did not refill due to drought. Cotton received three to four applications of 25 to 30 mm of water in 2000 and 2001 and was not irrigated beyond applications needed at planting in 2002 and 2003. During the 2001, 2002, and 2003 cotton growing season, soil temperature and soil water measurements were made at three depths (10, 30, and 60 cm) in one replication of each cover crop treatment using thermocouples and Watermark (Irrometer Co., Riverside, CA) soil moisture sensors. These data, along with air temperature and rainfall, were recorded using a field-based data logger. Weather data (rainfall and air temperature) for other periods of the year were obtained from the Vogtle Electric Generating Plant weather station located approximately 5-km east of the research site near the Georgia–South Carolina border.

Cotton stands, plant height, biomass, and N content were determined at 4 to 8 wk after planting. Samples were collected 27 June 2000, 19 July 2001, 15 July 2002, and 24 June 2003. Plant samples were processed as described previously for the cover crop biomass and then analyzed for C and N content using NIRS. Cotton yield was determined by mechanically picking four to six rows in each subplot. Soils were sampled at

0- to 2.5-, 2.5- to 7.5-, 7.5- to 15-, 15- to 30- and 30- to 60-cm depths in the spring and fall of each year to evaluate cover crop influences on soil C and N accumulation. Soils were dried at 55°C (Haney et al., 2004) for 5 to 7 d until dry, ground to pass a 1-mm sieve and then analyzed using an automated combustion type C and N analyzer.

Economic returns from the cover crop and tillage systems were estimated using enterprise budget worksheets from Clemson University (Ferreira, 2005). Cost per hectare for cover crop seed was \$44.03, \$55.50, \$34.26, \$36.63, \$74.00, \$111.01, and \$51.80 for Austrian winter pea, balansa clover, black oat, crimson clover, hairy vetch, and rye, respectively. Fertilizer N cost and payments for lint and cotton seed were set at 2005 prices of \$1.08, \$1.32, and \$0.10 kg^{-1} for all years of the study (Ferreira, 2005). Returns above variable costs were estimated for each treatment in each year and subjected to analysis of variance. Irrigation costs were not included in the estimates.

Statistical analyses of the data were performed using the MIXED procedure of the Statistical Analysis System (SAS Institute, 2004). The experimental design was a split block or strip–strip plot with three replications. Plot treatments were assigned in 1999 and the same plots were used each year for each cover crop (not rerandomized). Analyses were conducted as described in Littell et al. (1996) for a strip-strip plot experiment. Replication and year were random effects while cover crop and tillage were fixed effects. Interaction effects were entered into the model as random and fixed effects as appropriate. Means and differences among means were determined using the LSMEANS statement (diff and pdiff options) in PROC MIXED. The SAS macro PDMIX800 (Saxton, 1998) was used to convert the probability values for testing pairwise differences among means to letter groups, where means with a common letter were not statistically different at an α level of 0.05.

RESULTS

Weather

The Southeast experienced a prolonged drought during 1998 though 2002 with weather conditions (Fig. 1) for cover crop and cotton growing seasons to be less than favorable (USGS, 2003). Rainfall was below normal during 2000 and 2001, was near normal in 2002, and was above normal during 2003. Rainfall from 1 October to 31 December amounted to 203, 149, 67, and 377 mm for 1999, 2000, 2001, and 2002, respectively. Deviations from long-term average rainfall resulted in deficits of 330, 470, and 330 mm at cotton planting in 2000, 2001, and 2002 while in 2003 there was an excess of 129 mm rain. Rainfall deficits increased an additional 125 and 105 mm by 1 August of 2000 and 2001, respectively. Near normal rainfall fell during the summer of 2002 following cotton planting but soil water availability at planting was below normal. During 2000, 2001, and 2002 no irrigation water was used after 1 July, while in 2003 irrigation was not used beyond planting and establishment.

Temperatures from cover crop planting until 1 December were similar for the 4 yr, averaging between 12 and 16°C (Fig. 2). Periods of very cold weather were experienced each year with the most prolonged being from 19 Dec. 2000 to 11 Jan. 2001 when average temperatures were near or below 0°C, with 3 d having lows near −6°C. A similar but shorter period of cold weather occurred in mid-January 2003 with lows below −6°C for three consecutive days. Accumulation of growing degree days (GDD base 4.4°C) from planting to killing of the cover crops in mid-April was more favorable in 1999–2000 and 2001–2002 (1500 GDD) than during 2000–2001 and 2002–2003 (1200 and 1100 GDD, respectively). During the cotton growing season accumulation of GDD (base 15.5°C) (Ritchie et al., 2004) on 1 August was similar for the 4 yr (720–820 GDD). The number of GDD accumulated by 1 September were 1100, 1068, 1094, and 1000, in 2000, 2001, 2002, and 2003 and had increased to 1225, 1190, 1316, and 1115 by 1 October which exceeded the GDD needed for crop maturity (>1100).

Cover Crop Growth and Nitrogen

As would be expected from the difference in conditions experienced each year, growth and biomass production for the cover crops differed among years (Table 1). The type of tillage used during the cotton growing season had no effect on the following cover crop growth. Good growing conditions and earlier planting in the 1999–2000 growing season resulted in greater biomass production compared to the other years. The freezing period in the winter of 2000–2001 caused damage to most of the cover crops and reduced growth. Dry weather in the winter of 2001–2002 contributed to limited biomass production by the cover crops. Even with the variability among years, there were some differences in biomass and N content among the cover crops. No other cover crop produced more biomass than rye in any year and, when averaged over years, rye produced more biomass than the other cover crops. Crimson clover and balansa clover produced less biomass than other cover crops in 2000 and one or both were in the group producing the least biomass in all years. Crimson clover and balansa clover appeared to be N limited, even though we used fresh inoculants each year, possibly indicating poor nodulation except for the last year when the appearance of these two legumes improved.

Bruce et al. (1995) indicated that more than 12 Mg ha^{-1} of biomass is needed to improve productivity of soils of the Southeast and that cover crops were essential for attaining this level of biomass input. Cereal rye consistently produced more biomass than the other cover crops which demonstrates the reason for its popularity as a cover crop in the Southeast. Black oat produced less biomass than rye but the amounts were sufficient for good ground cover at planting. It is likely that late planting and dry weather during the cover crop growing period significantly influenced biomass production in the experiment. Delaying cover crop planting until early November following cotton harvest reduces biomass production (Bauer and Reeves, 1999) and is problematic in the Southeast. There continues to be a need for cover crops that can be planted in November or December that produce significant quantities of biomass in the spring.

Cover crop N content like biomass was greater in 1999–2000 than in the other years (data not shown). Averaged over the 4 yr, hairy vetch contained the greatest N content averaging over 100 kg N ha^{-1}. Austrian winter pea produced the most N during the 2001 season and similar amounts of N as hairy vetch in 2002. Using the non-

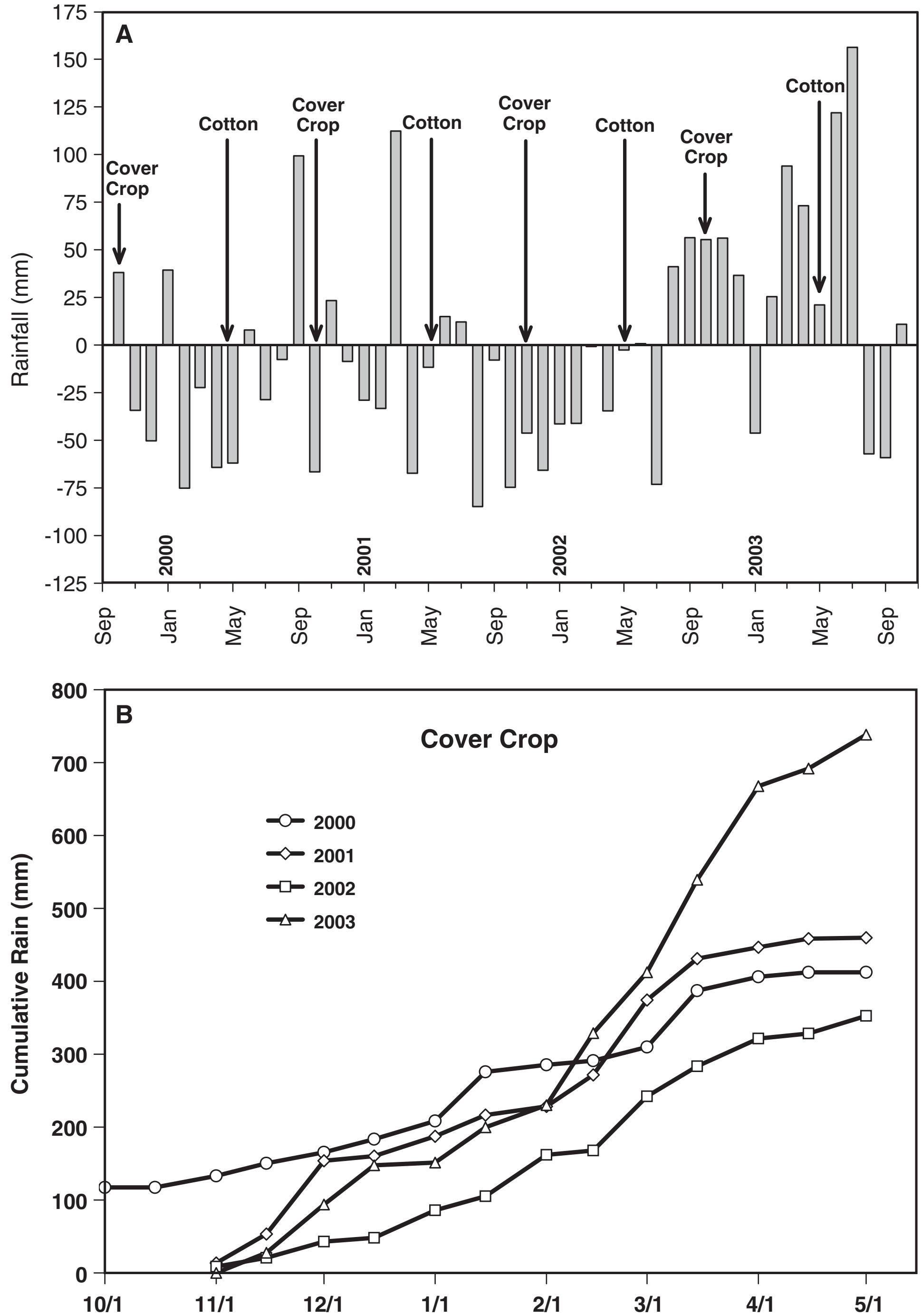

Fig. 1. Continued on next page.

legumes as an indication of available soil N, hairy vetch and Austrian winter pea fixed from 40 to 60 kg N ha^{-1} while balansa clover and crimson clover were apparently not fixing N since they contained similar amounts of N as the nonlegumes (40 kg N ha^{-1}). Legume cover crops can be a good source of N for summer crops because about half of the N in the residues can be mineralized in the first 4 wk after desiccation (Wilson and Hargrove, 1986; Schomberg and Cabrera, 2001). Our results indicate that hairy vetch and Austrian winter pea offer the greatest potential for reducing fertilizer N applications in cotton. These legumes could provide similar amounts of N as considered available following peanut (*Arachis hypogaea* L.) (35–45 kg N ha^{-1}) (Mitchell, 2000). In Georgia, the N recommendation for cotton grown in rotation with peanut is 35 to 45 kg N ha^{-1} thus reducing by more than half the 80 to 90 kg N ha^{-1} recommended for continuous cotton (Harris and Baker, 1997). Availability of cover crop N to cotton should be greater than from peanut because cover crops are terminated near cotton planting while N from peanut residues may be leached below the rooting zone, depending on rainfall during the winter.

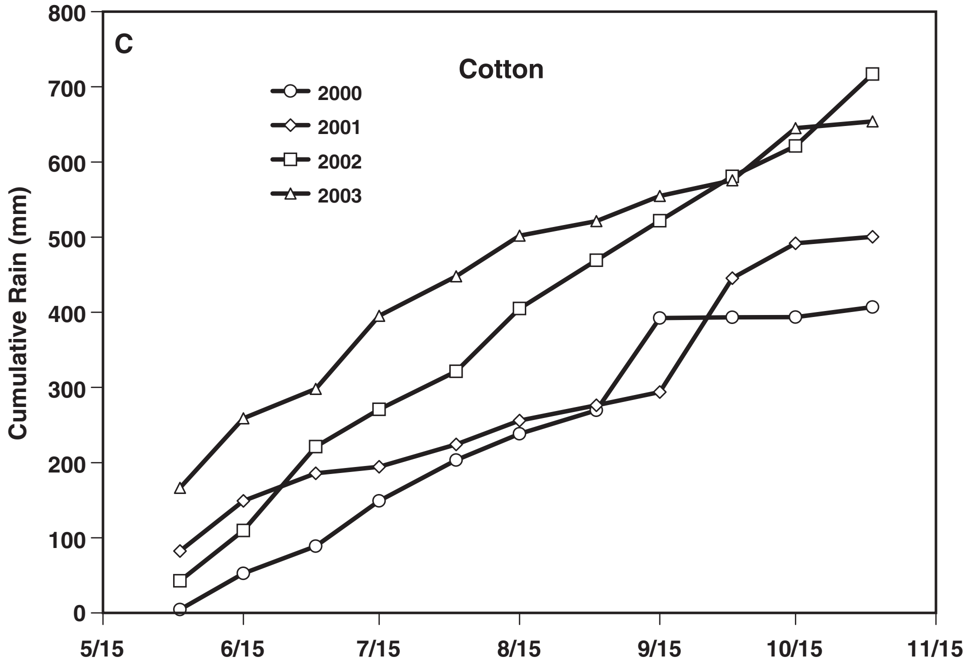

Fig. 1. Deviation from (A) historic average rainfall at Waynesboro, GA and cumulative rainfall amounts for the (B) cover crop and (C) cotton growing seasons.

Rye, black oat, and oilseed radish residues contained around 40 kg N ha^{-1}. Availability of N from oilseed radish and black oat would most likely be slightly greater than from rye since they have a lower C/N ratio (30 vs. 43). Residues with a C/N ratio above 30 can immobilize soil N during the decomposition process while a C/N ratio below 30 is needed before net N mineralization occurs (Schomberg et al., 1994). A controlling factor will be the maturity of the cover crops at the time of termination, with more mature residues having greater C/N ratios (Ashford and Reeves, 2003).

Using cover crops on this soil with conservation tillage increased the soil C content at the soil surface (0–2.5 cm) from May of 2000 to November 2003 from 11.5 to 14.6 g kg^{-1}. The increase in soil C was similar among cover crops and tillage treatments. Although rye and black oat had a trend of greater biomass production, this was only measured for the aboveground biomass. Belowground biomass production may have been a contributing factor to not observing a difference among the cover crops. Samples below the surface layer did not indicate a change in soil C over time and averaged 11.56, 9.55, and 5.34 g kg^{-1} for the 2.5 to 7.5, 7.5 to 15, and 15 to 30 cm depths, respectively.

Cotton Growth and Yield

Number of plants per meter of row, plant height, plant total N, and plant weight of cotton at 30 to 45 d after planting were used to evaluate cover crop and tillage influences on early season cotton growth. Parameter responses were variable across years (Table 2) but tillage and cover crop interacted in 2000 and 2002. In 2000, there were more plants following balansa clover in the no-tillage plots than in the strip-tillage plots (15.4 vs. 12.9 plants m^{-1}) while the opposite was observed for black oat (13.0 vs. 13.7 plants m^{-1}). Plant populations following the other cover crops were not different between the two types of tillage. In 2002, Austrian winter pea, black oat, and crimson clover had slightly more plants m^{-1} in the strip-tillage plots than in the no-tillage plots while there were no differences due to tillage for the other cover crops. The small but statistically significant differences in stand counts would not be expected to influence cotton yields because counts were well within recommended numbers of 7 to 13.5 plants per m^{-1} (Bednarz et al., 2000).

Cotton plant heights early in the growing season were significantly influenced by cover crop all 4 yr (Table 2). Cotton following black oat was as tall as or taller than cotton following the other cover crops. Cotton plots following rye or Austrian winter pea were also among the tallest in 3 out of 4 yr. Plants following oilseed radish had similar plant heights as those following black oat and rye in 2001 and 2003. Cotton plants were consistently shorter following crimson clover and balansa clover. Tillage interacted with cover crop in 2000 as a result of a difference in cotton plant heights following Austrian winter pea. Following Austrian winter pea, cotton averaged 1 cm taller with strip-tillage than with no-tillage, whereas there was no influence of tillage for the other cover crops.

Differences in early season cotton N content were observed in 2001 and 2003 but not in 2000 and 2002 or when evaluated across years (Table 2). In 2001, cotton N content was 50% lower following rye in no-tillage than in the strip-tillage plots while there were no differences between tillage treatments for other cover crops. Averaged over tillage treatments in 2001, early season cotton plant N content was greater following Austrian winter pea, hairy vetch, and oilseed radish than following

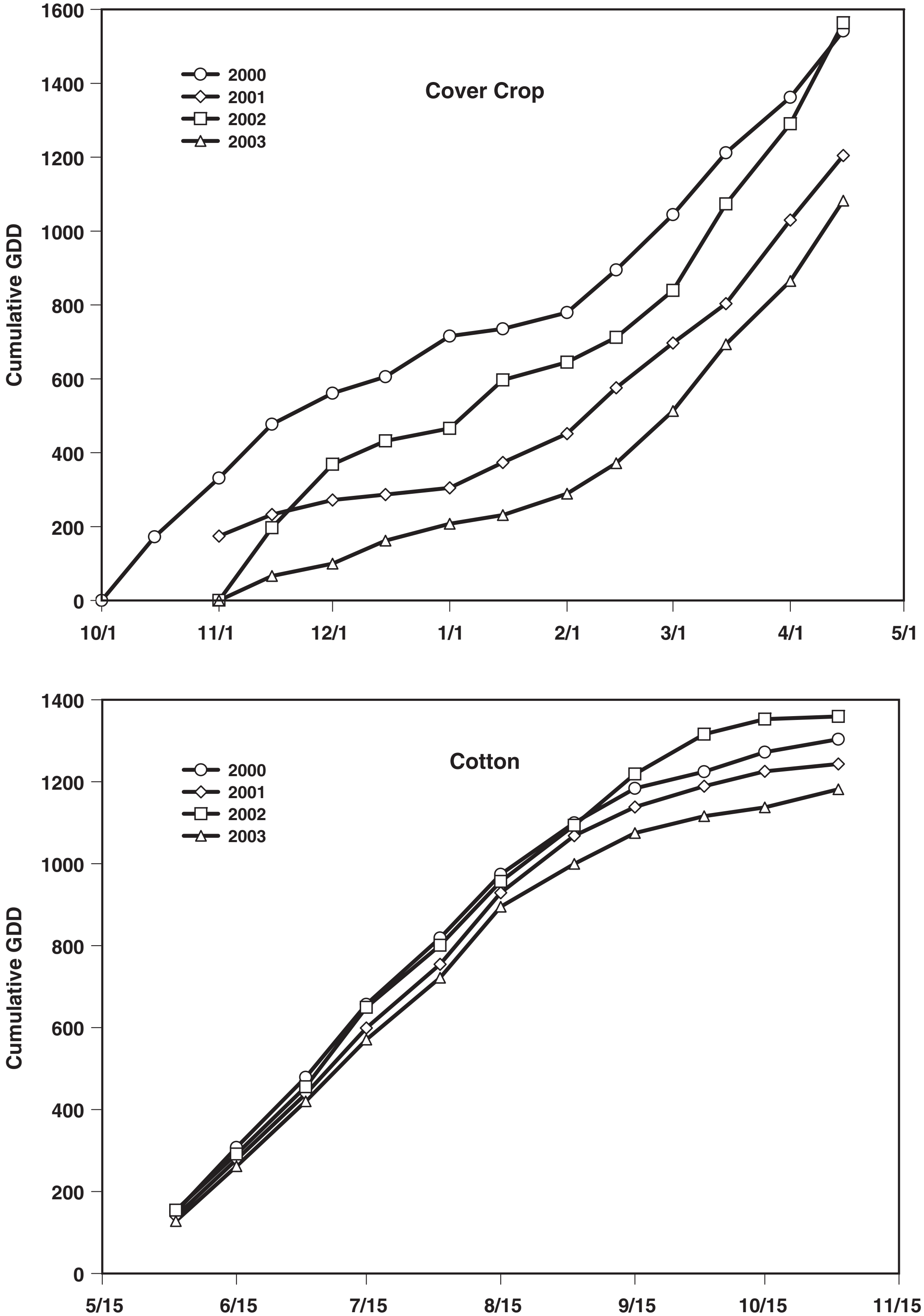

Fig. 2. Cumulative growing degree days (GDD) during the cover crop (base 4.4°C) and cotton (base 15.5°C) growing periods.

crimson clover. As was noted earlier, nodulation may have been limited for crimson clover. In 2003, cotton plant N content was greater following rye and black oat than following the other cover crops. Rye had a greater C/N ratio than the other cover crops all years except 2002 when all of the cover crops had C/N ratios <20. Crop residues with C/N ratios >30 are considered to have a greater potential for N immobilization (Doran and Smith, 1991) which we observed in 2001 where cotton following rye had a lower N content compared to

Table 1. Cover crop biomass and N content for 4 yr at Waynesboro, GA.

	Plant weight					Total N				
Crop	2000	2001	2002	2003	4 yr avg.	2000	2001	2002	2003	4 yr avg.
	kg ha^{-1}									
Austrian winter pea	3644†b‡	2727b	2135b	1867d	2595bc	106.7b	89.1a	87.7a	52.2c	83.8a
Balansa clover	2124c	1590cd	1137c	2477d	1848c	44.9de	32.1cd	30.2c	53.6c	40.3b
Black oat	5920a	2660b	2112b	1908d	3117b	80.1bc	28.0cd	76.1a	22.0d	51.3b
Crimson clover	1724c	913d	1440c	3217bc	1848c	36.9e	23.6d	42.5bc	74.0b	44.5b
Hairy vetch	4329b	2157bc	2023b	3333ab	2956bc	148.8a	74.0b	87.6a	95.9a	101.2a
Oil seed radish	3893b	2703b	1902b	2487cd	2746bc	70.4cd	34.2cd	46.6b	32.2d	45.7b
Rye	7031a	4207a	3207a	3987a	4582a	57.6cde	38.8c	76.7a	31.6d	51.2b
No-tillage		2350a	2022a	2876a			44.1a	64.7a	53.3a	
Strip-tillage		2495a	1965a	2631a			47.2a	63.2a	50.0a	

† Cover crop means are estimated over two tillage systems and three replications. Tillage means are estimated over all seven cover crop treatments and three replications.
‡ Different letters within a column indicate significantly different means between cover crops or tillage at $\alpha \leq 0.05$.

cotton following other cover crops. In contrast, rye and black oat had C/N ratios greater than the other cover crops in 2003 but cotton had a greater N content following these two cover crops. This result is somewhat contrary to what was expected.

Early season plant weight was influenced by cover crop two of 4 yr. A tillage influence on cotton plant weight was observed only in 2001 when plants in the strip-tillage treatment were 12% larger than those in the no-tillage treatment. In 2001, early season cotton plant weights were greater following black oat and Austrian winter pea than following balansa or crimson clover. In 2003, plant weights were greater following rye or black oat than the other cover crops. When data were evaluated across years, cotton cover crops did not influence plant weight ($P = 0.08$).

We also evaluated late season (predefoliation) plant weight and total N contents in 2000, 2001, and 2002 (Table 3). Type of cover crop influenced cotton plant total N content in 2001 and 2002 and cotton plant weight in 2000 and 2001 ($P = 0.06$) (Table 3). When averaged across years, late season cotton plant weight and total N content were influenced by cover crop but not by type of tillage. Cotton following hairy vetch and Austrian winter pea had greater plant weight and total N compared to following balansa clover and crimson clover.

Seed cotton yields were variable across years (Table 4). Due to the limited water availability and severity of the drought during the first 3 yr of the study, yields were below the long-term county average but were similar to average county yields for these years. Due to yield variability cover crop did not significantly influence seed cotton yield in 2000, 2001, or 2002 ($P \approx 0.30$). Even when the data were combined across years, no significant relationship was detected between cover crop biomass and cotton yields (-0.11, $P = 0.09$). Differences in yield due to cover crop were observed in 2003 ($P < 0.01$) with cotton following black oat, rye, and oilseed radish having greater yields than following the other four cover crops. Plants in some areas of the field in 2003 were stunted

Table 2. Cover crop and tillage influence on cotton stands, plant height, biomass, and N content 4 to 6 wk after cotton planting.

	No. of plants					Plant height				
Crop	2000	2001	2002	2003	4 yr avg.	2000	2001	2002	2003	4 yr avg.
	m^{-1}					cm				
Austrian winter pea	13.7†ab‡	8.8a	10.1abc	9.8a	10.6a	26.0ab	59.2ab	61.6abc	24.8b	42.7bc
Balansa clover	14.2ab	10.5a	11.0a	9.7a	11.3a	24.8b	49.2c	58.5bcd	21.4c	38.5d
Black oat	15.0a	9.2a	10.5ab	10.6a	11.3a	31.2a	61.3a	65.3a	30.7a	47.1a
Crimson clover	13.0b	10.3a	9.1c	10.0a	10.5a	22.6b	52.0bc	55.9d	21.3c	37.8d
Hairy vetch	13.2b	9.0a	10.3ab	9.3a	10.5a	25.1b	53.3bc	56.7cd	23.4bc	39.5cd
Oil seed radish	13.4b	9.6a	9.8bc	10.0a	10.7a	23.6b	54.2abc	58.3bcd	28.9a	41.5bcd
Rye	14.0ab	9.4a	10.8ab	10.4a	11.2a	31.7a	53.3bc	63.3ab	31.6a	45.2ab
No-tillage	13.7a	9.5a	9.8a	9.3a	10.5a	27.2a	54.0a	57.6a	25.9a	41.2a
Strip-tillage	13.8a	9.6a	10.7a	10.6a	11.2a	25.6a	55.2a	62.3a	26.1a	42.4a

	Plant total N					Plant wt.				
Crop	2000	2001	2002	2003	4 yr avg.	2000	2001	2002	2003	4 yr avg.
	g plant^{-1}					g plant^{-1}				
Austrian winter pea	0.15a	0.49a	0.54a	0.13b	0.32a	3.1a	18.5a	16.1a	3.6b	10.3a
Balansa clover	0.14a	0.40bc	0.53a	0.10b	0.29a	2.9a	15.3bc	16.2a	2.9bc	9.4a
Black oat	0.20a	0.45abc	0.54a	0.20a	0.35a	4.2a	18.3a	16.4a	5.3a	11.0a
Crimson clover	0.12a	0.38c	0.55a	0.09b	0.29a	2.4a	14.7c	16.0a	2.4c	9.0a
Hairy vetch	0.16a	0.46ab	0.58a	0.12b	0.33a	3.2a	17.4ab	15.6a	3.3bc	9.8a
Oil seed radish	0.12a	0.47ab	0.55a	0.11b	0.31a	2.6a	16.8abc	15.1a	3.6b	9.5a
Rye	0.18a	0.40bc	0.50a	0.19a	0.32a	3.7a	16.9abc	15.0a	5.1a	10.2a
No-tillage	0.16a	0.40a	0.55a	0.13a	0.31a	3.2a	15.9b	15.9a	3.8a	9.7a
Strip-tillage	0.15a	0.47a	0.53a	0.14a	0.32a	3.1a	17.8a	15.7a	3.6a	10.0a

† Cover crop means are estimated over two tillage systems and three replications. Tillage means are estimated over all seven cover crop treatments and three replications.
‡ Different letters within a column indicate significantly different means between cover crops or tillage at $\alpha \leq 0.05$.

Table 3. Cover crop and tillage influence on cotton N content and biomass late in the cotton growing season.

Crop	Plant total N 2000	Plant total N 2001	Plant total N 2002	Plant total N 3 yr avg.†	Plant wt. 2000	Plant wt. 2001	Plant wt. 2002	Plant wt. 3 yr avg.†
	g plant^{-1}							
Austrian winter pea	1.62‡a§	1.64a	1.29ab	1.50a	99.7ab	75.7a	61.2a	78.6a
Balansa clover	1.32a	0.97c	0.98b	1.10b	84.4c	47.7b	50.8a	61.4c
Black oat	1.29a	1.29abc	1.02b	1.20ab	90.0abc	64.8ab	49.3a	67.6abc
Crimson Clover	1.46a	1.03bc	1.10ab	1.21ab	88.0bc	47.2b	53.1a	63.2bc
Hairy vetch	1.87a	1.57a	1.17ab	1.50a	105.0a	78.1a	53.8a	77.9ab
Oilseed radish	1.43a	1.36abc	1.44a	1.43ab	83.5c	61.3ab	60.5a	69.1abc
Rye	1.41a	1.48ab	1.17ab	1.35ab	78.8c	68.8ab	53.8a	67.3abc
No-tillage	1.49a	1.27a	1.20a	1.32a	88.2a	60.5a	55.2a	68.1a
Strip-tillage	1.48a	1.39a	1.14a	1.33a	91.6a	66.3a	54.1a	70.5a

† Late season samples were not collected in 2003.
‡ Cover crop means are estimated over two tillage systems and three replications. Tillage means are estimated over all seven cover crop treatments and three replications.
§ Different letters within a column indicate significantly different means between cover crops or tillage at $\alpha \leq 0.05$.

due to nematodes and the degree of stunting appeared to be less in plots where black oat, rye, and oilseed radish had been grown as cover crops. We did not sample plots to determine if there was a correlation between nematode root damage and cover crops but suspect that nematode populations had built up during the 4 yr of continuous cotton. A weak relationship was found between cover crop N content and cotton yields (-0.15, $P = 0.02$). A slightly stronger negative relationship was found between cover crop biomass and early season cotton plant N content (-0.32, $P < 0.01$). Cover crop N content and early season cotton plant N content were not correlated (0.03, $P = 0.65$).

Tillage influenced yield in 2001 with a greater yield in the strip-tillage plots. Tillage influences on yields in 2002 and 2003 had P values of 0.13 and 0.18 with a consistent trend of greater yield with strip-tillage than with no-tillage. When data were combined across years, both cover crop and tillage significantly influenced seed cotton yields. Greatest yields were observed following black oat and rye while lowest yields occurred for cotton following balansa clover, crimson clover, and hairy vetch. Averaged over the 4 yr, strip-tillage increased yields by 192 kg ha^{-1} over no-tillage. We suspect that this difference was primarily due to improved water extraction within the strip-tillage treatment. Soil water contents measured to 60 cm for the 3 yr we collected data indicated slightly greater water extraction with strip-tillage; however, only one replication was instrumented and we could not test for statistical differences by analysis of variance. After rainfall events and during periods of high evapotranspiration, available water decreased more rapidly beneath the strip-tillage plots possibly indicating a greater rooting density (data not shown) (Table 4).

The influences of cover crops and tillage systems on estimated annual returns above variable costs are presented in Table 4. The legume systems were given a credit for the amount of N in residues above that in nonlegumes assuming the legume N was fixed N that would become available during the cotton growing season. Estimated returns above variable costs were different among the cover crops in 2000 and in 2003. The 4-yr average estimated return was not significantly different among cover crops ($P = 0.13$). Black oat tended to produce the greatest average return followed by rye and Austrian winter pea. The larger degree of variability from year to year limited detection of differences between tillage treatments most years but the 4-yr average indicated an advantage for using strip-tillage even after discounting the cost for the strip-tillage operation.

SUMMARY AND CONCLUSIONS

Among the seven cover crops evaluated, rye and black oat appear to be the best choices for conservation tillage systems on sandy southeastern coastal plain soils. The consistent biomass production and good cotton yields following rye demonstrate why it is a popular

Table 4. Cover crop and tillage influence on seed cotton yield and returns above variable costs.

Crop	Seed cotton yield 2000	Seed cotton yield 2001	Seed cotton yield 2002	Seed cotton yield 2003	Seed cotton yield 4 yr avg.	Returns above variable costs 2000	Returns 2001	Returns 2002	Returns 2003	Returns 4 yr avg.
	kg ha^{-1}					\$ ha^{-1}				
Austrian winter pea	1422†a‡	1422a	1872a	933b	1412bc	380ab	399a	633a	72c	371a
Balansa clover	1398a	1429a	2028a	802b	1414bc	314bc	335a	692a	−16c	331a
Black oat	1350a	1600a	2000a	1830a	1695a	254cd	404a	644a	542a	461a
Crimson clover	1322a	1260a	1730a	978b	1323c	287bc	252a	532a	129bc	300a
Hairy vetch	1513a	1492a	1682a	879b	1392c	449a	396a	489a	56c	347a
Oil seed radish	1345a	1534a	1608a	1639a	1532abc	174d	287a	332a	350ab	286a
Rye	1437a	1431a	1986a	1678a	1633ab	289bc	285a	618a	433a	406a
No-tillage	1381a	1362b	1718a	1089a	1387b	299a	284b	491a	131a	301b
Strip-tillage	1415a	1544a	1970a	1408a	1584a	314a	390a	635a	316a	414a

† Cover crop means are estimated over two tillage systems and three replications. Tillage means are estimated over all seven cover crop treatments and three replications.
‡ Different letters within a column indicate significantly different means between cover crops or tillage at $\alpha \leq 0.05$.

cover crop in many areas. Our results for black oat are similar to those of Bauer and Reeves (1999), who found a slight yield advantage for cotton following black oat compared to rye although black oat was more susceptible to very cold temperatures that commonly occur in one out of 3 yr in the region. The greater yields following black oat resulted in a return slightly greater than with rye and would be a good choice for most producers. The effect of strip-tillage for disrupting compacted soil layers has been demonstrated to be an effective method for influencing water availability and crop growth on soils of the Coastal Plain. Combining black oat or rye with strip-tillage can help cotton producers achieve higher yields and economic returns on sandy soils in the Southeastern Coastal Plain while improving soil C levels. The combination can also help producers qualify for higher levels of conservation compliance within the Natural Resources Conservation Service's Conservation Security Program.

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